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INFLUENCE OF CHANGING BACKGROUND ON CHRIS/PROBA DATA OVER AN HETEROGENEOUS CANOPY

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ABSTRACT

The spaceborne ESA-mission CHRIS-Proba (Compact High Resolution Imaging Spectrometer-Project for On-Board Autonomy) provides hyperspectral and multi-directional data of selected targets spread over the world. While the spectral information content of CHRIS/Proba data is able to assess the biochemistry of a vegetation canopy, the directional information can describe the structure of an observed canopy. In this study we proposed to demonstrate the effects of changing background on the hemispherical-directional reflectance factor (HDRF) of a coniferous forest based on a multi-temporal CHRIS-Proba data set (summer / winter scene) over the Swiss National Park. However, the data status of the CHRIS-Proba observations did only allow for an appropriate pre-processing of the summer scene. Instead the complex 3-D radiative transfer model FLIGHT was employed to assess the influence of changing background (understory vs. snow) within a forest canopy. The study shows the enhanced potential of the directional and spectral information content of CHRIS/Proba for mapping heterogeneous canopies using a multi-temporal data set.

INTRODUCTION

The spectral reflectance of a vegetation canopy is known to be primarily a function of the foliage optical properties, the canopy structure, the understory and soil background reflectance, the illumination conditions, and finally the viewing geometry (1). In the case of a coniferous canopy the interaction of incident radiation is dominated by its complex 3-D canopy structure, which has a significant impact on the degree of anisotropy in the reflected radiation field. However, the anisotropy of the observed canopy also depends strongly on the spectral contrast between the canopy and ground cover in the background (2). A bright ground cover, e.g. snow surface, should enhance the anisotropy and consequently the exploitation of the HDRF observed by CHRIS/Proba for sub-pixel heterogeneity and canopy structure.

To demonstrate the effects on the anisotropy of a coniferous canopy with changing background we acquired and pre-processed a multitemporal CHRIS/PROBA data set. CHRIS/PROBA (Compact High Resolution Imaging Spectrometer-Project for On-Board Autonomy) is ESA spaceborne mission providing hyperspectral and multidirectional data of selected targets spread over the world (3). We selected two scenes with spectrally contrasting backgrounds, one summer CHRIS acquisition with understory background and one in wintertime with snow cover in the background. Both data set had to be geocorrected and radiometrically corrected for a coherent comparison of the HDRF following a pre-processing approach taking into account the complex geometry of CHRIS acquisitions (4). However, the status of the data only allowed for the pre-processing of the summer scene. Along with the spaceborne data also spectro-directional ground data have been acquired with the FIGOS Goniometer over a meadow and a snow surface, allowing for a validation of the obtained top-of-canopy HDRF.

Due to the lack of a complete multi-temporal CHRIS data set the complex 3-D radiative transfer model FLIGHT was employed to assess the influence of changing background (understory vs. snow) within a forest canopy. The simulated anisotropy of the heterogeneous canopy over the respective background is presented and discussed. The observed enhanced directional response of a forest canopy over snow background could ultimately lead to an improved estimation of canopy structure.

TEST SITE AND FIELD DATA

The test site for this study is located in the eastern Ofenpass valley, which is part of the Swiss National Park (SNP). The Ofenpass represents an inner-alpine valley on an average altitude of about 1900 m a.s.l with annual precipitation of 900-1100 mm. The south-facing Ofenpass forests, the location of the field measurement, are largely dominated by mountain pine (*Pinus montana ssp. arborea*) and some stone pine *(Pinus cembra* L.) (5, 6). These forest stands can be classified as woodland associations of *Erico-Pinetum mugo* (5). Unique ground based characterization of the canopy structure, biochemistry and optical properties of the canopy elements were conducted in summer 2002 using various instruments, ranging from non-destructive spectroradiometric measurements to dry biomass estimation of needles (7).

Parallel to the CHRIS/PROBA acquisition of the 26.06.2004 spectro-directional ground data have been acquired with the FIGOS Goniometer over an alpine meadow (Figure 1). The canopy development of meadow was still in an early phenological stage with sparse vegetation cover due to the alpine altitude of the site. Also field spectra of several land surface types were collected with the ASD FieldSpectrometer in nadir measurement configuration, 1.5 m above the ground and within 2 hours of solar noon under clear sky conditions. All spectra were converted to absolute reflectance by reference measurements over a Spectralon panel with known spectral properties.

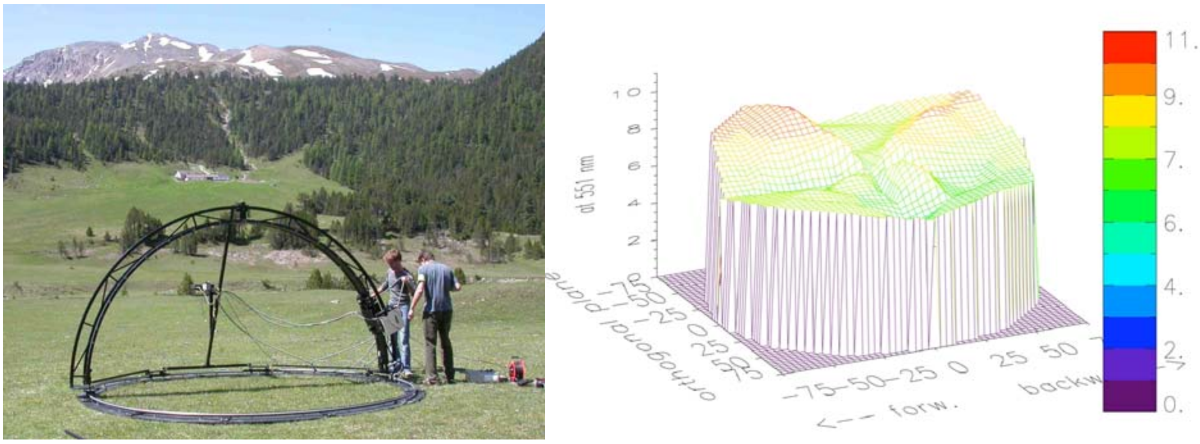

Figure 1: Acquisition of HDRF data on an alpine meadow in the Swiss National Park using RSL's Field Goniometer System (FIGOS); Right: resulting HDRF measurements at wavelength 551 nm.

CHRIS DATA ACQUISITION

CHRIS/PROBA acquisitions over the SNP site amounted in the time between December 2003 and February 2005 to 7 scenes. The CHRIS acquisitions have been ordered to be taken in the Land Mode 3, but several of the early scenes were acquired in the Chlorophyll Mode 4. The scene considered in this study has been taken the 27.06.2004 under partly cloudy conditions (1/8th cloud cover).

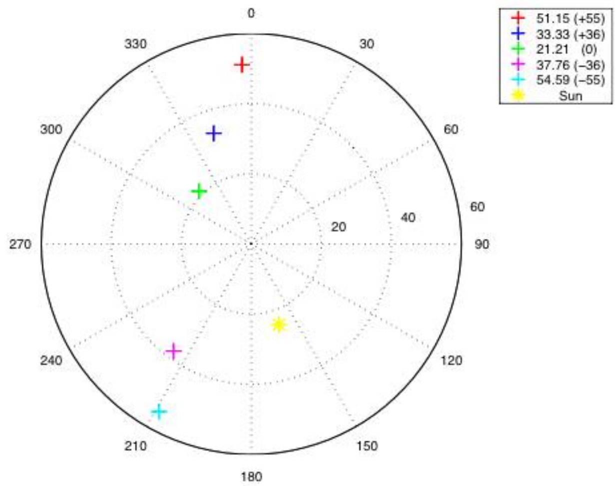

Figure 2: Polar plot of CHRIS image acquisition and illumination geometry as of June 27, 2004.

Table 1: CHRIS specifications for Land Mode 3

Spatial Sampling	Image area	View angles	Spectral bands	Spectral range
17m @ 556 km altitude	13 x 13 km (744x748 pixels)	5 nominal angles @ 55°, 36°, 0°, -36°, -55°	18 bnads with 6-33 nm width	447 – 1035 nm

GEOMETRIC PROCESSING

Given the fact that the Swiss National Park (SNP) test site is situated in high mountainous, rugged terrain, a parametric approach for geometric correction of each of the five data sets of a full CHRIS acquisition scenario (five different viewing angles) is applied. The approach is based on a 3D physical model developed by Toutin (8, 9), which is implemented in the commercially available image processing software PCI/Geomatica (10). A physical model can mathematically describe all distortions of the platform (position, velocity, orientation), the sensor (view angles, IFOV, panoramic effects), the Earth (ellipsoid, relief) and the cartographic projection. Such a model needs both orbit and sensor information, as well as a small number of ground control points (GPC's) to compute and refine the parameters of the mathematical model (9). Typical orbit and sensor information required comprises sensor altitude, orbital period, eccentricity, actual inclination, sensor across- and along track angle and IFOV (3). Required image scene information are pixel spacing at nadir, the approximate scene center, as well as the underlying ellipsoid and a digital elevation or surface model.

The number of GCP's required is a function of e.g., available orbit and sensor information, GCP accuracy and final expected accuracy, but does normally not exceed 10 points. Generally, an iterative least-square adjustment process is applied when more GCP's than the minimum number required by the model (as a function of unknown parameters) are used (9). A digital surface model derived from ERS1/2 tandem data is used for the part of the CHRIS scene that lies within Switzerland (spatial resolution 25m), whereas SRTM-3 data (3 arc-seconds, spatial resolution 90m, interpolated to 25m) is used for the neighbouring areas in Northern Italy. Given the coarser resolution of the elevation data in the southern part of the CHRIS scene and the absence of almost any potential GCP's in this region due to its remote location, an attempt was made to select GCP's both within the whole CHRIS image, but also within the specific region of interest (the Ofenpass valley) in order to increase the locational accuracy within this specific area. High locational accuracy of the five CHRIS scenes after geometric correction is a prerequisite for reliable retrieval of HDRF information from the data set. Locational accuracy under one pixel root mean square error (RMSE) was achieved for the respective scenes when optimized to the region of interest.

A qualitative example of the accuracy that could be achieved by applying a parametric geocoding approach to the CHRIS data set of the SNP test site is given in Fig. 3 for FZA=0° (the actual observation angle is +21.21°). It is obvious from Fig. 3 that the overlaid vector data consisting of roads, hiking trails and rivers fits well to the CHRIS image data after geometric correction.

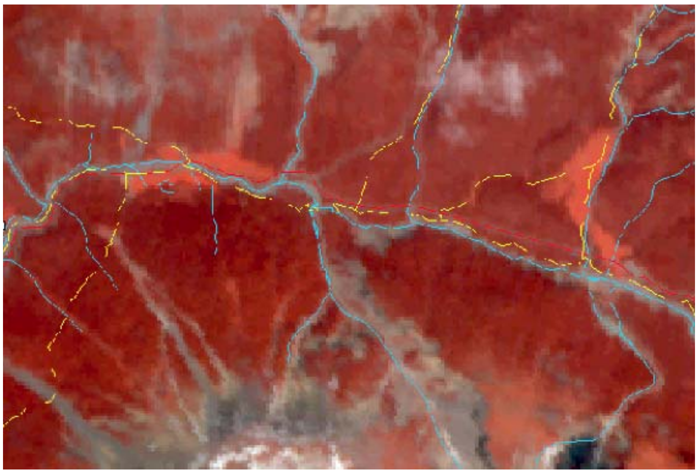

Figure 3. Geometrically corrected CHRIS image (FZA=0°) of the SNP test site with overlaid vector data (CHRIS bands 1,5 and 16).

ATMOSPHERIC PROCESSING

Atmospheric correction of the CHRIS radiance data is performed using ATCOR-2/3 (11, 12), which is based on MODTRAN-4. While ATCOR-2 is generally used to atmospherically correct data from optical spaceborne sensors assuming flat terrain conditions, ATCOR-3 accounts for terrain effects by incorporating DEM data and their derivatives such as slope and aspect, sky view factor and cast shadow. ATCOR-3 is therefore suitable for atmospheric correction of sensor data acquired over rugged terrain. ATCOR-3 has recently been adapted to include the option to process tilted sensors by accounting for varying path lenghts through the atmosphere and varying transmittance. CHRIS Land Mode 3 has newly been implemented in ATCOR-2/3. Given the high altitude of the SNP test site (1900 msl), a horizontal visibility of 50km and a rural aerosol model are assumed for atmospheric correction. The results of geometric and atmospheric processing of the June 27, 2004 CHRIS scene over the SNP test site can be seen in figure 5. The FZA = +36° scene was acquired exactly in the solar principle plane, resulting in strong sun glint effects present on Lake Livigno (see Fig. 5d).

Validation of the atmospheric processing for the June 27, 2004 CHRIS scene over the SNP test site is performed through comparison of corrected CHRIS spectra versus dedicated spectral ground measurements (meadow and gravel) performed with an ASD spectroradiometer during CHRIS data take. Figure 4 shows a comparison of atmospherically corrected CHRIS data (FZA=0° data set) and spectral ground truth for an alpine meadow. It can be concluded from the validation that the atmospherically corrected CHRIS data fits the ground truth data well, except for the Land Mode 3 channels 1, 17 and 18. All other channels lie within the ±1 stdev margins of the ground truth.

The distinct HRDF signatures for a number of different land surface types, present in the SNP, as retrieved from pre-processed CHRIS data is given in Figure 5.

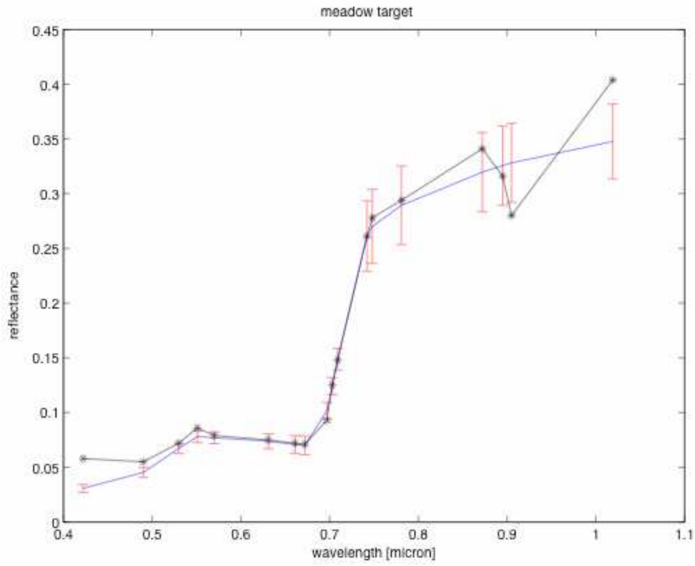

Figure 4: Comparison of atmospherically corrected CHRIS data (Land Mode 3, black line) and ground measured spectral data for an alpine meadow (blue line). The variation of ±1 stdev of the ground truth measurements from the mean is indicated by red bars.

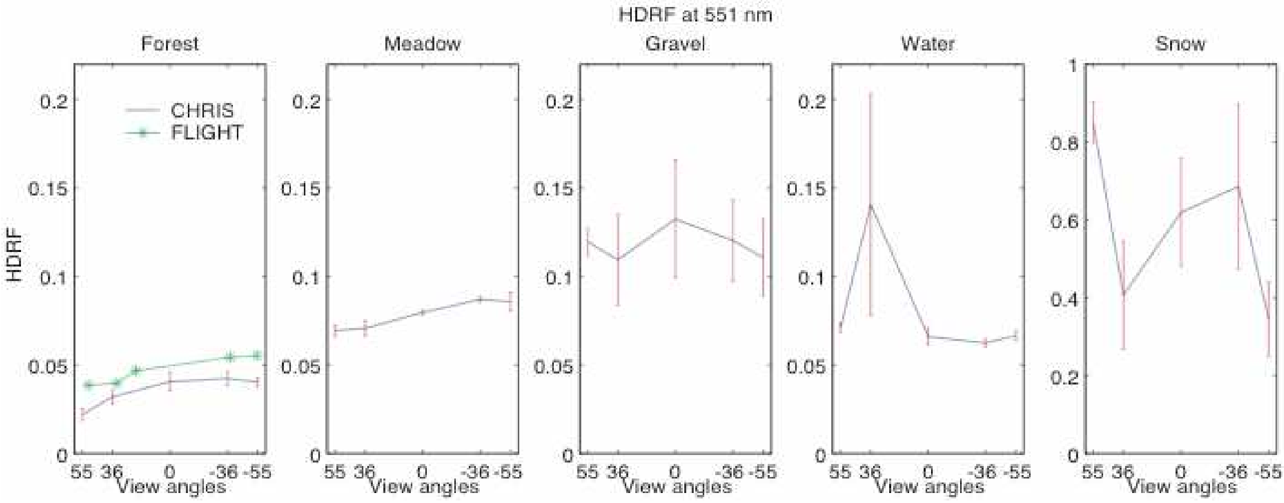

Figure 5: Hemispherical-directional Reflectance Factor (HDRF) measured by CHRIS over different land surface types. FLIGHT simulated forest BRF is added for comparison with measured CHRIS HDRF.

DIRECTIONAL EFFECTS WITH CHANGING BACKGROUND

The 3-D radiative transfer model FLIGHT (13) coupled to the leaf model PROSPECT (14) was employed to simulate multi-directional and hyperspectral canopy reflectance. The model PROSPECT, which provided the foliage optical properties as a function of the biochemistry, characterized the radiative transfer at the foliage level. FLIGHT is a three dimensional ray tracing model using Monte Carlo techniques for the radiative transfer within crown boundaries and deterministic ray tracing between the crowns and other canopy components. The canopy structure is represented by geometric primitives defined by the crown shape and size, tree height, tree position and distribution. The geometric representation of FLIGHT deals explicitly with crown overlapping, mutual shading and multiple scattering between crowns.

In order to study the effect of changing background on the anisotropy of the canopy reflectance, two simulations of the coupled radiative transfer models were performed. The parameterizations of the two simulations only differed in the spectral properties of the background. The background was represented by spectral field measurements of an active understory for the summer and of a snow surface for the winter simulation (Figure 6).

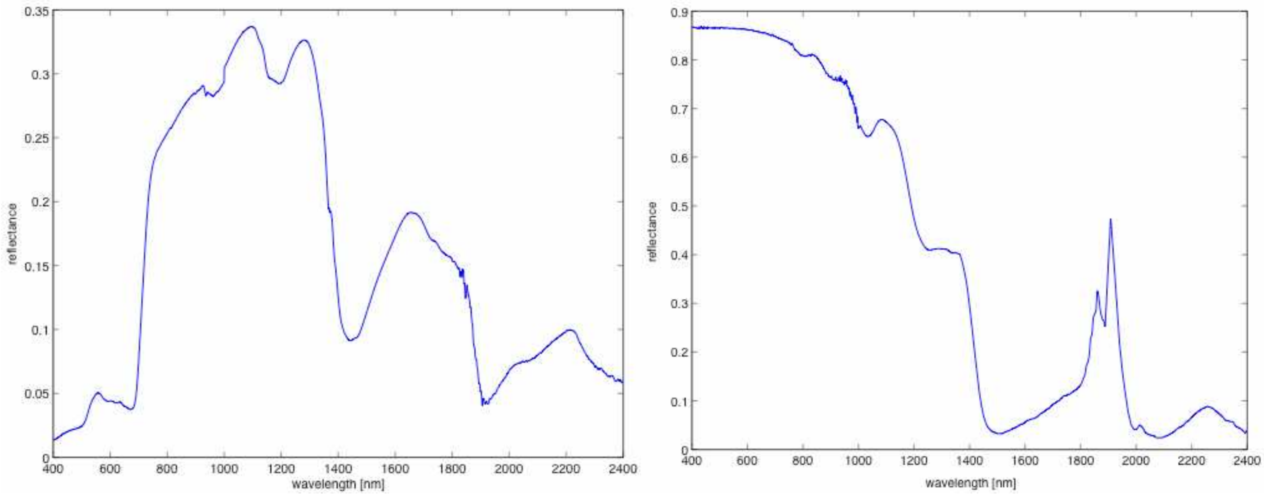

Figure 6: Spectral properties of background for the summer and winter parameterization representing respectively the reflectance spectrum of a typical understory and a snow surface.

The forest representation for the radiative transfer common to the two simulations was parameterized at the foliage and canopy level by the average field data of the core test site LWF1 describing the biochemical and biophysical properties of the canopy (Table 2). The complex scene of the heterogeneous forest was represented within FLIGHT by taking into account the geometry of single trees composing the scene. The relevant information on the tree position, height and crown geometry was provided by the LIDAR data set (15, 16). The reconstruction of the observed forest scene based on the LIDAR derived tree geometry allowed consequently to consider the actual canopy structure (e.g. fcover) as well as the detailed heterogeneity of the canopy within the radiative transfer.

Table 2: Field observations of canopy variables including relative measurement errors relevant for the canopy parameterization of the RTMs PROSPECT and FLIGHT. The spectral properties of the woody parts and understory were characterized by spectroradiometric field measurements.

	Unit	LWF1
Foliage parameters (PROSPECT)		
Water content	g/cm2	0.047 (7.5%)
Dry matter	g/cm2	0.038 (7.5%)
Chlorophyll content	μg/cm2	61.8 (1.54%)
Mesophyll structure	Unitless	3.78 (22%)
Canopy structure (overstory)		
LAI	Unitless	2.18 (13%)
Fractional cover	%	0.55 (13%)
Wood fraction	%	0.3
Crown shape		Cone

The two simulations resulted in the Bidirectional Reflectance Factor (BRF) typical for the respective background changing with season (Figure 7). The angular sampling of the BRF provided by FLIGHT was set to five degrees for zenith and azimuth. A number of 10 million photons simulated by FLIGHT assured a theoretical relative standard error below 1%. Nevertheless, considerable noise is apparent in the summer BRF simulations due to the relative low reflectance level.

The comparison of the two simulations highlights the effect of changing canopy background on the BRF in absolute reflectance level and specifically in the form of observed anisotropy. The BRF observed in summer over an understory background with low spectral contrast relative to the crown results in a relatively low and flat directional response. Whereas, the BRF over a bright snow background exhibits a very pronounced anisotropy on a relatively high reflectance level. The forest BRF over snow reaches a distinct maximum at the hotspot forming a bell-shape BRF. Widlowski (2001) identified a similar BRF form to be typical for heterogeneous canopies characterized by background with high spectral contrast. The bell-shaped BRF is caused by the decreasing fraction of visible relative brighter background with increasing oblique viewing angles. The characteristics of the BRF form should thus be sensitive to the heterogeneity and canopy structure of the observed forest.

For the summer situation similar directional behaviour could be detected in simulated and actual CHRIS observations (Figure 5a). A complete multi-temporal CHRIS data set will thus hopefully confirm the effects of changing background with season apparent in the simulated observation also for a CHRIS winter scene.

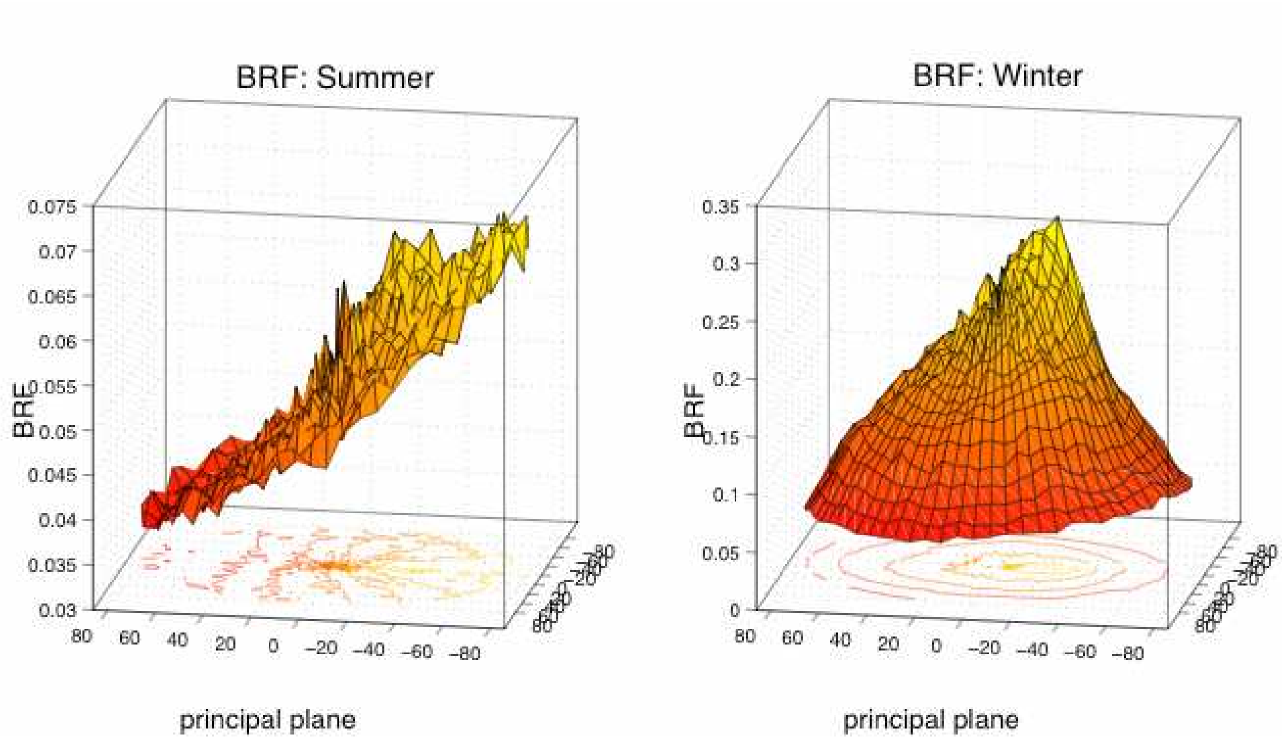

Figure 7: Simulated Bidirectional Reflectance Factor (BRF) @ 551nm for the same forest scene parameterization but with changing background (left: summer scene - understory, right: winter scene - snow)

CONCLUSIONS

The results indicate the potential of the synthesis between the spectral, directional and temporal information dimension provided by the spaceborne imaging spectrometer CHRIS/Proba. Simulated BRF of a forest canopy over a background with high spectral contrast to the canopy, e.g. snow surface of a winter scene, enhanced significantly the directional signature of the observed canopy. In forest stands the 3D structure of the canopy is dominating the spectral and directional canopy reflectance response. The heterogeneity and canopy structure of the observed forest should thus be assessed with increased accuracy based on the enhanced directional information of multi-temporal CHRIS data set (17, 18).

Furthermore, the successfully implemented geometric and radiometric pre-processing of the multi-angle CHRIS/Proba data is able to provide a consistent multi-temporal data set. Consequently improved canopy structure retrieval based on the enhanced anisotropy in the winter scene could help to restrain the assessment of the forest biochemistry in the summer scene. This approach requires a relatively constant heterogeneity and canopy structure of the forest, which could be assumed in the observed case of a coniferous forest.

Future research will focus on the characterization and quantification of the anisotropy in relation to its underlying causes, canopy structure and heterogeneity.

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